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## Assessing how the history of e-cigarette and cigarette use are associated with the developmental course of marijuana use in a sample of United States adolescents

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### Abstract

**Background**—The purpose of this study was to determine the developmental course of marijuana use among adolescents based on their history of cigarette and e-cigarette use among a national U.S. sample of adolescents who were followed over a four year time-period.

**Methods**—The data for this study used four waves of the Population Assessment of Tobacco and Health (PATH) Study provided by a panel of 12 to 17-year-olds at Wave 1 (n=11,059) who completed each of the four annual waves of the adolescent/adult survey. We examined recent use (i.e., past 30-day) of e-cigarettes, cigarettes, and marijuana use at each of the four waves.

**Results**—Respondents who had a history of non-concurrent dual use (AOR = 1.67, 95% CI = 1.24, 2.24) and a history of concurrent dual use (AOR = 1.67, 95% CI = 1.40, 1.99) had greater odds of past 30-day marijuana use when compared to respondents who had a history of past 30-day e-cigarette use only. Interaction effect models found that e-cigarette only users were at lower risk for past 30-day marijuana use at Wave 1, however, the risk of past 30-day marijuana use increased at a faster rate across the four waves for e-cigarette only users when compared to their peers who used cigarettes or a combination of cigarettes and e-cigarettes.

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#### Contributors Statement

Philip Veliz – Designed the study, wrote the manuscript, managed the secondary data, and conducted analyses.

Sean McCabe – Helped design the study, reviewed the manuscript, and provided feedback on the analyses.

Rebecca Evans-Polce – Helped design the study, reviewed the manuscript, and provided feedback on the analyses.

Carol Boyd – Helped design the study, reviewed the manuscript, and provided feedback on the analyses.

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All of the authors have nothing to disclose.

Conflict of interest:

The authors of this Research Letter have no conflicts of interest to report.

**Conclusion**—While concurrent and non-concurrent dual use was strongly associated with marijuana use over the study period, marijuana use increased at a faster rate across the four-year span of the study among e-cigarette only users.

## Keywords

e-cigarettes; cigarettes; marijuana

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## 1. Introduction

Prior longitudinal studies have found that both cigarette and e-cigarette use is associated with marijuana use among adolescents and young adults (Audrain-McGovern et al., 2018; Dai et al., 2018; Evans-Polce et al., 2020; Ramo et al., 2012; Unger et al., 2016). Studies also indicate that the risk of marijuana use is highest among adolescents who engage in dual use (i.e., individuals who use both cigarettes and e-cigarettes) (Dai and Hao, 2017; Kristjansson et al., 2015; McCabe et al., 2019; McCabe et al., 2017). For instance, more than 80% of U.S. high school students with a lifetime history of dual use had also used marijuana (McCabe et al., 2017). These findings derived from cross-sectional and short-term data (e.g., one year) indicate the need for long-term prospective studies to examine the longitudinal association between marijuana use and different combinations of cigarette and e-cigarette use among adolescents (Evans-Polce et al., 2020). Given recent increases in both marijuana and e-cigarette/e-product use among U.S. adolescents (Cullen et al., 2018; Johnston et al., 2020; Miech et al., 2019), it is necessary to understand how the history of cigarette and e-cigarette use during adolescence (i.e., no use, e-cigarette use only, cigarette use only, and concurrent and non-concurrent dual use) is associated with the developmental course of marijuana use over a longer time period. Accordingly, the purpose of this study was to determine the different trajectories of marijuana use among adolescents based on their history of cigarette and e-cigarette use among a national U.S. sample of adolescents who were followed over a four-year time-period.

## 2. Methods

### 2.1. Sample

This study used data from the Population Assessment of Tobacco and Health (PATH) Study, a nationally representative panel of youth (ages 12 to 17 at Wave 1) who were assessed at four separate time points, Wave 1: September/2013-December/2014; Wave 2: October/2014-October/2015; and Wave 3: October/2015-October/2016; and Wave 4: December/2016-January/2018 (United States Department of Health and Human Services, 2020). The PATH Study used a four-stage stratified area probability sample design. Audio computer-assisted self-interviewing (ACASI) was conducted and on-screen displays and flashcards were used to aid adolescent respondents. The retention rate within the adolescent sample was 79.5% by Wave 4. The retained youth sample (including those who aged into the adult sample) included 11,059 respondents.

## 2.2. History of past 30-day cigarette and e-cigarette use

Past 30-day cigarette and e-cigarette use were measured with two variables across each wave of the survey (Waves 1 through 4): “In the past 30 days, on how many days did you smoke cigarettes?”, and “In the past 30 days, on how many days did you use an e-cigarette?” Response options ranged from 0 to 30 days. These measures were then recoded as a binary variable ‘past 30-day use’ versus ‘no past 30-day use’. In order to best isolate the patterns of past 30-day use across the four waves of the survey, we combined these two measures at each wave (i.e., Wave 1 through 4) to construct a mutually exclusive variable with five unique categories: (1) no cigarette or e-cigarette use during the past 30-days during the four waves of the study (2) only e-cigarette use (only indicated past 30-day e-cigarette use during at least one wave of the survey), (3) history of non-concurrent cigarette use and e-cigarette use (indicated past 30-day use of either e-cigarette or cigarette use during at least one wave of the survey, but not both during the same wave [i.e., non-concurrent dual use]), (4) only cigarette use (only indicated past 30-day cigarette use during at least one wave of the survey), and (5) dual use (concurrent past 30-day cigarette and e-cigarette use during at least one wave). For the analyses, this independent variable capturing history of cigarette and e-cigarette use across the four waves was treated as a time invariant variable in order to clearly assess the different trajectories of marijuana use during this time-period.

## 2.3. Frequency of Past 30-day cigarette and e-cigarette use

Two additional independent variables measured at each wave assessed past 30-day cigarette frequency (i.e., 0-30 days) and e-cigarette frequency (i.e., 0-30 days). For the analysis both of these measures were treated as continuous measures that were time-varying.

## 2.4. Past 30-day marijuana use

The major outcome variable, marijuana use, was assessed with one item at each wave. The question asked if respondents “used marijuana in the past 30 days”. Response options included “Yes” or “No”. For the analyses the variable was coded as a binary outcome (i.e., Yes = 1, No = 0) and was treated as a time-varying outcome.

## 2.5. Control variables

In order to account for potentially confounding factors, all of the multivariable analyses controlled for sex, race, Hispanic ethnicity, respondent’s age at Wave 1, household income, and U.S. region. Each of these sociodemographic were treated as time-invariant characteristics. Additionally, a single time-invariant composite measure was constructed to assess lifetime use of other tobacco products.

## 2.6. Analyses

Binary logistic regression models were fitted using the generalized estimating equations (GEE) methodology with an autoregressive correlation structure to assess the association between history of past 30-day use of cigarettes/e-cigarettes and the *time-varying* outcome for past 30-day marijuana use (Hanley et al., 2003; Zeger et al., 1988). Models with and without covariates are provided along with the unadjusted odds ratio (OR), adjusted odds ratio (AOR) and 95% confidence intervals. GEE models were estimated with the full sample

using respondents with no past 30-day cigarette or e-cigarette use during the four waves of the study as the reference group. Moreover, models using a smaller subset of respondents that indicated any past 30-day cigarette or e-cigarette use during the study period were estimated using respondents that only engaged in past 30-day e-cigarette use during the study period as the reference group. Finally, in order to assess potential differences in trajectories of marijuana use between each of the four cigarette/e-cigarette groups, interaction effects were estimated based on history of past 30-day cigarette/e-cigarette use and wave (i.e., time) of the survey. These models treated wave as a continuous time-varying variable; interaction effects were assessed by taking the product of history of past 30-day cigarette/e-cigarette use (time-invariant) and wave of survey (time-varying). All conducted analyses used weights and designated variables to account for the complex sampling design. Stata 15.0 was used for all analyses. Sample sizes may vary given that listwise deletion was used when estimating these models in Stata.

### 3. Results

Table 1 provides the descriptive statistics for the full panel sample ( $n = 11059$ ) and the sample who indicated past 30-day use of either cigarette or e-cigarette use during at least one wave ( $n = 2902$ ). Among the longitudinal sample, 27% of the sample indicated past 30-day use of either cigarettes or e-cigarettes during the study period. Table 1 also shows that the prevalence of e-cigarette use only, cigarette use only, dual use, and marijuana use increased over the four waves of the study. With respect to history of past 30-day use of cigarettes and e-cigarettes over the four waves among past 30-day cigarette and/or e-cigarette users ( $n = 2902$ ), the largest group was concurrent dual users (34.5%), followed by only e-cigarette users (34.4%), only cigarette users (25.3%), and non-concurrent dual users (5.8%).

Table 2 provides the results from the GEE analyses assessing history of past 30-day cigarette/e-cigarette use and past 30-day marijuana use. Assessing the full sample (see Analysis 1) shows that any history of past 30-day use of cigarettes or e-cigarettes over the study period was associated with greater odds of past 30-day marijuana use when compared to peers who did engage in any past 30-day use of cigarette/e-cigarette use. For instance, respondents who indicated any history of concurrent dual use had roughly four times greater odds of indicating past 30-day marijuana use when compared to respondents who had no history of past 30-day cigarette/e-cigarette use (AOR = 4.56, 95% CI = 3.82, 5.45) when adjusting for both frequency of use, wave of survey, and other sociodemographic factors. The odds of past 30-day marijuana use were greater at later waves when compared to Wave 1; odds of past 30-day marijuana use significantly increased across each wave (refer to 95% CI's for the analyses using the full models).

Table 2 also provides the results assessing only respondents who had a history of past 30-day cigarette/e-cigarette use (see Analysis 2). Accordingly, respondents who had a history of non-concurrent dual use (AOR = 1.67, 95% CI = 1.24, 2.24) and a history of any concurrent dual use (AOR = 1.67, 95% CI = 1.40, 1.99) had greater odds of past 30-day marijuana use when compared to respondents who had a history of past 30-day e-cigarette use only. No differences in the odds of past 30-day marijuana use were found between respondents with a

history of past 30-day cigarette use only and respondents with a history of past 30-day e-cigarette use only.

The interaction effect model provided in Table 2 found statistically significant differences in the linear increase between e-cigarette only users and the three other groups that had a history of cigarette use only or a history of both cigarette and e-cigarette use (see Analysis 3). The main effects show that at baseline, respondents who indicated a history of cigarette use only or a combination of cigarette and e-cigarette use had higher odds of past 30-day marijuana use when compared to respondents who had a history of e-cigarette use only. However, the interaction effects show that when compared to e-cigarette only users, the positive linear increase in past 30-day marijuana use is weaker for non-concurrent dual users, cigarette use only users, and concurrent dual users. In other words, while e-cigarette only users were at lower risk for past 30-day marijuana use at Wave 1 when compared to their peers who used cigarettes or a combination of cigarettes and e-cigarettes, the risk of past 30-day marijuana use increased at a faster rate across the four waves for e-cigarette only users. Additional analyses found no differences in the linear increase between the other three groups of respondents with a history of cigarette use or combination of cigarette and e-cigarette use (supplemental figure A provides the observed results to show this interaction graphically).

#### 4. Discussion

This is one of the first studies to assess the developmental course of marijuana use based on the history of cigarette and e-cigarette use during adolescence over a four-year time period. The findings from the present study extends prior research that has found an association between marijuana use and different combinations of cigarette and e-cigarette use over shorter time periods (Dai and Hao, 2017; Kristjansson et al., 2015; McCabe et al., 2019; McCabe et al., 2017). In particular, adolescents who reported concurrent dual use or non-concurrent dual use of cigarettes and e-cigarettes were at the greatest risk of marijuana use during the four waves of the study. Moreover, while adolescents who had a history of only e-cigarette use were at lower risk of marijuana use when compared to their peers who used cigarettes or some combination of cigarette and e-cigarettes, the odds of marijuana use during the study period among e-cigarette only users were roughly three times higher when compared to adolescents who did not engage in any past 30-day cigarette or e-cigarette use.

Additionally, the results of this study also provide new evidence that the developmental course of marijuana use is significantly different among adolescents who have a history of e-cigarette use only when compared to their peers who use cigarettes or some combination of cigarette and e-cigarettes. In particular, e-cigarette only users had a lower risk of marijuana use at the first wave when compared to adolescents who used cigarettes or some combination of cigarettes and e-cigarettes. However, marijuana use increased at a faster rate across the four-year span of the study among e-cigarette only users that could be missed in shorter term studies.

The results of this study suggest that the use of e-cigarettes alone, regardless of frequency of use, was associated with a steeper increase in the risk of using marijuana when compared to

their peers who only used cigarettes or a combination of cigarettes and e-cigarettes over the study period. This is particularly concerning given the increase in e-cigarette use among adolescents (Cullen et al., 2018; Johnston et al., 2020; Miech et al., 2019), and the growing proportion of adolescent marijuana users who report vaping as their route of administration (Knapp et al., 2019; Trivers et al., 2018). Based on the results of this study, greater effort needs to be focused on how e-cigarette/e-product use (e.g., flavorings) may be an initial pathway to marijuana use. While this study expands upon our knowledge of how e-cigarettes are associated with the developmental course of marijuana use among adolescents, several limitations should be noted. First, this study relied on self-reported data and may be subject to various types of respondent bias. Moreover, there are a number of confounding factors not included in the analysis that may account for the association between cigarette/e-cigarette use and marijuana use (e.g., availability, peer use/norms). Finally, this study could only assess a general measure of past 30-day marijuana use and could not determine whether adolescents used some type of e-product to smoke this substance. Despite these issues, this study provides needed epidemiological information to understand how e-cigarettes are associated with the increased risk of marijuana use as adolescents' age into young adulthood. While dual users are at an increased risk for marijuana use, adolescent's with only a history of e-cigarette use appear to be a vulnerable group whose risk of marijuana use sharply increases during this phase of development. These findings reinforce the need to target adolescents who use e-cigarettes on either an experimental or frequent basis given that this type of substance use behavior is a potential marker for later risk behaviors like marijuana use.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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### Highlights

- Dual users are at an increased risk for marijuana use.
- Marijuana use increased at a faster rate among e-cigarette only users.
- E-cigarette use is a significant marker for later risk behaviors like marijuana use.

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**Table 1.**

Sample characteristics with the adolescent panel sample

	Total Sample		Past 30-day Nicotine/Tobacco Users	
	Total n	n = 11059	Total n	n = 2902
<b>Sex<sup>a</sup></b>				
Males	5610	51.2%	1594	55.5%
Females	5385	48.8%	1305	44.5%
<b>Race<sup>b</sup></b>				
White	7077	69.6%	2015	75.2%
Black	1706	16.1%	318	11.6%
Other	1623	14.3%	444	13.3%
<b>Hispanic ethnicity<sup>b</sup></b>				
Non-Hispanic	7671	77.4%	2122	79.5%
Hispanic	3156	22.6%	742	20.5%
<b>Age (Wave 1)<sup>c</sup></b>				
12 to 14 years of age	5341	47.5%	777	26.2%
15 to 17 years of age	5678	52.5%	2125	73.8%
<b>Household income<sup>d</sup></b>				
\$24,999 or lower	1700	13.4%	437	13.3%
\$25,000 to \$49,999	2128	17.4%	459	14.2%
\$50,000 to \$99,000	2451	22.2%	541	18.8%
\$100,000 or higher	2349	24.1%	482	18.4%
Missing	2392	22.9%	983	35.4%
<b>U.S. region<sup>e</sup></b>				
Northeast	1587	16.3%	444	17.1%
Midwest	2440	22.2%	725	24.5%
South	4127	37.0%	1027	35.4%
West	2866	24.6%	706	23.0%
<b>Past 30 day marijuana use</b>				
Marijuana use (Wave 1)	561	5.2%	443	15.5%
Marijuana use (Wave 2)	962	9.1%	725	26.3%
Marijuana use (Wave 3)	1209	11.7%	845	31.2%
Marijuana use (Wave 4)	1626	16.0%	1036	39.8%
<b>Past 30 day cigarette/e-cigarette use</b>				
No Use (Wave 1)	10307	93.8%	2227	77.1%
No Use (Wave 2)	9590	89.7%	1679	60.7%
No Use (Wave 3)	9001	84.7%	1171	42.5%
No Use (Wave 4)	8397	80.3%	692	25.2%

	Total Sample		Past 30-day Nicotine/Tobacco Users	
	Total n	n = 11059	Total n	n = 2902
E-cigarette use only (Wave 1)	170	1.6%	170	6.1%
E-cigarette use only (Wave 2)	308	3.1%	308	11.6%
E-cigarette use only (Wave 3)	576	5.6%	576	20.9%
E-cigarette use only (Wave 4)	689	7.0%	689	26.5%
Cigarette use only (Wave 1)	344	3.2%	344	11.8%
Cigarette use only (Wave 2)	489	4.5%	489	17.2%
Cigarette use only (Wave 3)	536	5.1%	536	19.3%
Cigarette use only (Wave 4)	780	7.4%	780	28.1%
Dual use (Wave 1)	151	1.3%	151	5.0%
Dual use (Wave 2)	282	2.7%	282	10.4%
Dual use (Wave 3)	480	4.6%	480	17.3%
Dual use (Wave 4)	510	5.3%	510	20.1%

Notes: n = unweighted sample size; Percentages and means incorporate baseline survey weights for the longitudinal sample; SE = standard error; Sample sizes may vary due to missing data.

<sup>a</sup> Sex of respondent was a derived variable (i.e., PATH constructed the variable) from the interview and included either 'Male' or 'Female'.

<sup>b</sup> Race/Ethnicity of respondent was a derived variable from the interview and included either 'White alone', 'Black alone', and 'Other'. Hispanic was derived from the interview and included either 'Hispanic' or 'Not Hispanic'.

<sup>c</sup> Age of respondent at Wave 1 was a derived variable from the interview and included either '12 to 14 years old' and '15 to 17 years old'. It should be noted that the public use files only provide dichotomous age ranges for the adolescent sample (i.e., 12 to 14, 15 to 17) and seven for the adult sample (18 to 24, etc... adolescent who age into the adult sample will only fall into his category. Below we provide the age ranges of respondents between Wave 1 and Wave 4 based on the possible three age brackets from the adolescent public use sample (unweighted estimates are provided): Wave 1, 12-14 (52.7%), 15-17 (47.3%), 18-24 (0%); Wave 2, 12-14 (35.7%), 15-17 (49.2%), 18-24 (15.1%); Wave 3, 12-14 (18.2%), 15-17 (51.4%), 18-24 (30.3%); Wave 4, 12-14 (1.9%), 15-17 (50.6%), 18-24 (47.5%).

<sup>d</sup> Household income was a derived variable from the interview and include five categories: 'less than \$10,000', '\$10,000 to \$24,999', '\$25,000 to \$49,999', '\$50,000 to \$99,999', and '\$100,000 or more'. The maximum income indicated in either Wave 2 through Wave 4 was used for the analysis. A derived variable for household income is not included at Wave 1. Missing data on this variable is due to the youth sample in Wave 1 moving to the adult sample in Wave 2.

**Table 2.**

Assessing how the history of e-cigarette and cigarette use is associated with the developmental course of marijuana use

	Past 30-day marijuana use (time-varying)	Past 30-day marijuana use (time-varying)
<b>Analysis 1 (Full Sample)</b>	<b>Full Sample Models (n=9,263)</b>	
<i>Time Invariant Variables</i>	<b>Unadjusted OR (95% CI)</b>	<b>Adjusted aOR (95% CI)</b>
<b>History of past 30 day use of cigarettes and e-cigarettes across all 4 waves</b>		
Did not use cigarettes or e-cigarettes	Reference	Reference
E-cigarette use only	5.46***(4.78,6.24)	2.96***(2.50,3.51)
Non-concurrent dual use	11.3***(8.91,14.4)	4.66***(3.45,6.29)
Cigarette use only	7.93***(6.88,9.14)	3.24***(2.69,3.89)
Any history of concurrent dual use	13.8***(12.2,15.6)	4.56***(3.82,5.45)
<i>Time Varying Variables</i>		
<b>Number of days used (past 30 days)</b>		
Number of days used e-cigarettes during the past 30 days	1.05***(1.04,1.06)	1.01** (1.00,1.02)
Number of days used cigarettes during the past 30 days	1.05***(1.04,1.06)	1.02***(1.01,1.03)
<b>Time</b>		
Wave 1	Reference	Reference
Wave 2	1.84***(1.69,2.02)	2.07***(1.85,2.32)
Wave 3	2.44***(2.21,2.68)	2.90***(2.56,3.27)
Wave 4	3.53***(3.20,3.88)	4.90***(4.34,5.52)
	<b>Past 30-day marijuana use (time-varying)</b>	<b>Past 30-day marijuana use (time-varying)</b>
<b>Analysis 2 (Only respondents with a history of 30-day cigarette/e-cigarette use)</b>	<b>Subgroup Sample Models (n=2,351)</b>	
<i>Time Invariant Variables</i>	<b>Unadjusted OR (95% CI)</b>	<b>Adjusted aOR (95% CI)</b>
<b>History of past 30 day use of cigarettes and e-cigarettes across all 4 waves</b>		
E-cigarette use only	Reference	Reference
Non-concurrent dual use	2.07***(1.60,2.67)	1.67***(1.24,2.24)
Cigarette use only	1.44***(1.23,1.70)	1.17 (.969,1.41)
Any history of concurrent dual use	2.52***(2.18,2.91)	1.67***(1.40,1.99)
<i>Time Varying Variables</i>		
<b>Number of days used (past 30 days)</b>		
Number of days used e-cigarettes during the past 30 days	1.02***(1.01,1.03)	1.01** (1.00,1.02)
Number of days used cigarettes during the past 30 days	1.03***(1.02,1.04)	1.02***(1.00,1.02)
<b>Time</b>		
Wave 1	Reference	Reference
Wave 2	1.92***(1.72,2.15)	2.02***(1.78,2.30)

	Past 30-day marijuana use (time-varying)	Past 30-day marijuana use (time-varying)
<b>Analysis 1 (Full Sample)</b>	<b>Full Sample Models (n=9,263)</b>	
<i>Time Invariant Variables</i>	<b>Unadjusted OR (95% CI)</b>	<b>Adjusted aOR (95% CI)</b>
Wave 3	2.45***(2.17,2.77)	2.57***(2.23,2.97)
Wave 4	3.63***(3.19,4.11)	4.05***(3.51,4.68)
	<b>Past 30-day marijuana use (time-varying)</b>	
<b>Analysis 3 (Interaction effect model)</b>	<b>Interaction Effect Model (n=2,351)</b>	
<i>Time Invariant Variables</i>	<b>Adjusted aOR (95% CI)</b>	
<b>History of past 30 day use of cigarettes and e-cigarettes</b>		
E-cigarette use only	Reference	
Non-concurrent dual use	3.06***(2.04,4.61)	
Cigarette use only	1.66***(1.22,2.26)	
Any history of concurrent dual use	2.78***(2.11,3.66)	
<i>Time Varying Variables</i>		
<b>Time</b>		
Continuous measure for Wave of PATH (Wave 1 = 0 to Wave 4 = 3)	1.87***(1.70,2.05)	
<b>Interaction Effects</b>		
Non-concurrent dual use X Time	0.716***(.591,.866)	
Cigarette use only X Time	0.833***(.732,.948)	
Any history of concurrent dual use X Time	0.759***(.676,.852)	

Notes: n = unweighted sample size; Analyses incorporate baseline survey weights for the longitudinal sample; SE = standard error; Sample sizes may vary due to missing data; All analyses control for sex, race, Hispanic ethnicity, respondent's age at Wave 1, household income, U.S. region, and lifetime use of other tobacco products.